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ALCOA RESEARCH LABORATORIES

ALCOA

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PROGRESS REPORT

Contract No. NAS 8-5452
Control No. TP 3-85364 (1F)
CPB 02-1170-63

# Development of a High Strength Aluminum Alloy, Readily Weldable in Plate Thicknesses, And Suitable for Application at -423°F (-253°C)

For the Period July 1, 1964 to July 31, 1964



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# DEVELOPMENT OF A HIGH STRENGTH ALUMINUM ALLOY, READILY WELDABLE IN PLATE THICKNESSES, AND SUITABLE FOR APPLICATIONS AT -423°F (-253°C)

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Progress Report 13

by

R. W. Westerlund

August 19, 1964

Alcoa Research Laboratories
Aluminum Company of America
New Kensington

## STATUS OF RESEARCH PROGRAM

During the past year (July 1963 to July 1964), the Alcoa Research Laboratories has conducted a research and development program under Contract NAS 8-5452. The objective was to develop a high strength, weldable aluminum alloy or alloys with good cryogenic notch toughness. To enable a continuation of the research and development work initiated last year, an extension to the above contract has been granted.

### COMPLETION OF FIRST YEAR PROGRAM

The major item to be completed is the evaluation of alloys M825 and M826, fabricated at Alcoa's Davenport Plant. The program includes tensile and notch-tensile tests at temperatures to -423°F and stress corrosion tests of parent plate and weldments. The tensile and notch-tensile properties at room temperature, -112°F and -320°F have been determined. Specimens from 1.0" plate of M825 have been sent to the sub-contractor for determination of the -423°F properties. Welded panels of M825 are prepared and specimens preparation is proceeding. M826 material is being reheat treated to achieve higher properties. Stress corrosion testing of both alloys has started.

### SECOND YEAR PROGRAM

The new experimental program will be conducted in two phases which will proceed essentially concurrently. Each phase will have subsections that will be interdependent and require progressive planning to make use of prior findings in programming succeeding experiments.

In Phase I the promising characteristics of two alloys resulting from the prior contract, M825 and M826, will be more fully evaluated with establishment of appropriate composition limits, optimum fabricating and heat treating practices, and minimum and typical mechanical properties. Table I shows the intended compositions of 14 alloys being fabricated to conduct the above program. Variations of M825 are intended to determine the effect of Cu level and Cd/Sn ratio on properties. Variations of M826 are centered on the Cu, Zr, Zn and Mg concentrations; the Cu and Zr variations were included, primarily, to see their effect on notch toughness. The above alloys have been cast and are now being fabricated at Alcoa Research Laboratories.

The evaluation of the alloys which are variations of M825 will be different from that for the M826 variations. Emphasis for the M825 type alloys will be upon strengths of parent metal and weldments prepared using 2319 and parent metal fillers. Determination of the notch-toughness for these alloys will be delayed, since they generally have good toughness. Detailed corrosion testing will be delayed until completion of a preliminary program relating aging treatment to stress corrosion. M826 will be fully evaluated: tensile and notch-tensile testing at room temperature and -320°F for parent metal and weldments prepared using M822 and parent metal fillers; stress corrosion testing of parent plate and weldments.

An important feature of Phase I will be the work to develop a weld filler alloy to provide higher weld efficiencies than those which can be achieved employing existing weld filler

compositions. Ten filler alloys were recently cast and their intended compositions are shown in Table I.

In Phase II new experimental alloys will be surveyed in a forward-looking program designed to test new concepts that have originated either from previous portions of the project, from literature surveys, or from theoretical considerations. Two variations of M825 having additions of 0.3 Li and 0.6 Li have been cast along with three variations of M826 having additions of 0.3 Li, 0.3 Ag and 0.3 Ca (Table I). The evaluation program for Phase II will be similar to that for Phase I.

## RESULTS AND DISCUSSION

### 2000 SERIES ALLOYS

Since the weld strengths of the 2000 series alloys have not been improved over those of 2219, the following program was conducted to increase the weld strengths by using different filler compositions. Two Al-Cu alloys containing Cd and Cd + Sn (M825) were welded as 0.125" sheet with 2319, M825, and three Al-Cu filler alloys containing 0.23 Cd, 0.12 Mg, or 0.53 Mg.

Tensile properties for the as-welded condition (naturally aged 25 days) and the post-weld aged condition (artificially aged 16 hours at 325°F) are shown in Table III. No filler provides consistently higher tensile strengths than 2319, although there are isolated cases of improved properties. Specimens with the bead-on generally failed at the edge of the weld where no reinforcement occurred. Bead-off specimens usually failed through the weld and would be expected to show

properties typical of the filler alloy. Therefore, it was surprising to see no effect of filler metal on bead-off tensile strengths. Post-weld aging raised strengths for both the bead-on and bead-off conditions, but was much more effective for the bead-off condition.

These same alloys had previously been welded at 0.525" plate, using 2319 filler. A comparison of the tensile strengths showed that the sheet had only slightly higher strengths than the plate.

Tables IV and V list the tensile and notch-tensile properties of several experimental 2000 series alloys and several commercial alloys at testing temperatures to -423°F. The latter alloys were tested since notch-toughness data using a $K_t = 10$ was desired to facilitate comparison with the properties of alloys developed under the contract. As shown, alloy M825 has greater strength than the commercial alloys and excellent notch toughness at cryogenic temperatures.

7000 SERIES ALLOYS

The weld properties of M791 and M793 0.525" plate welded with M822 filler alloy have been reported previously, but the locations of failure were not indicated. Table VI summarizes the weld properties and indicates the locations of failure. All the reduced section specimens and many of the full section specimens failed adjacent to the weld in the heat affected zone. The full section specimens that failed at the edge of the weld zone had tensile strengths approximately equal to the reduced section strengths, thus showing the two areas of the weld have

similar strengths. The macrographs in Figure 1 show the tendency for some of the full section specimens to fail in two locations: the lower macrograph shows failure adjacent to the weld with a crack at the edge of the weld, while the upper macrograph shows failure through both locations. Most of the edge-of-weld failures occurred with M791. This is attributed to M822 being of similar solute content to M791 but of higher solute content than M793.

In the final report for last year it was noted that the increase in tensile strength with decreasing testing temperature was different for the as-welded and post-weld aged conditions of specimens taken from the 7000 series welds. The ratio of tensile strength at -320°F to that at room temperature was about 1.1 for the as-welded condition and about 1.3 for the post-weld aged condition. Although no explanation of this can be given, fracture examination showed the location of failure for the as-welded condition changed from adjacent to the weld at room temperature to through the weld at -320°F, while the post-weld aged specimens failed adjacent to the weld at both testing temperatures.

Effect of Deformation on Toughness

The notch toughness of the 7000 series alloys has been found to decrease rapidly with decreasing testing temperature. The only method found so far of improving the cryogenic toughness is is the addition of Zr. The following program was initiated to see the effect of deformation (as part of the thermal treatment) on toughness. In most of the program, deformation was employed before aging but in a small portion deformation was used before solution heat treatment. The treatments given and the results obtained are presented in Table VII. For comparison purposes,

previous properties for treatments with no deformation are included.

Deformation before aging slightly lowers the strength and elongation at room temperature, while it increases the elongation slightly at -320°F. The notch-tensile ratio at room temperature is raised slightly by deformation, while the ratio at -320°F seems to depend on the alloy. Alloys containing Zr (M791 and M793) seem to have slightly lower toughness when deformed before aging while the opposite is true for the alloy with no Zr. Additional work seems warranted to verify if deformation before aging can improve the toughness of 7000 series alloys without Zr.

The effect of deformation before solution heat treatment on toughness is not clear. With 10% deformation, the material remained unrecrystallized and had similar tensile properties and slightly lower toughness at -320°F than material with no deformation. With 40% reduction before solution heat treatment, the material was partially recrystallized. The strengths were not affected but the room temperature toughness was higher and the -320°F toughness was much lower than material with no deformation.

## EVALUATION OF PLANT MATERIAL

The sheet and plate of M825 (Al-Cu-Cd-Sn) and M826 (Al-Zn-Mg-Zr) fabricated at Alcoa's Davenport Plant is now undergoing evaluation at Alcoa Research Laboratories. The evaluation program will concentrate on the properties of the 1.0" and 2.37" plate: tensile and notch-tensile properties of

parent and welded 1.0" plate; tensile and notch-tensile properties and resistance to stress corrosion in the short transverse direction of 2.37" plate.

Figure 2 shows the microstructure of 1.0" plate of M825 and M826. The M826 material is unrecrystallized while the M825 material is recrystallized.

The tensile properties of the various thicknesses are shown in Table VIII for M825 and in Table IX for M826. The strengths of M825 are not highly dependent on testing direction but do change slightly with thickness of material. The lower strengths of the 2.37" plate are attributed to the slow quenching rate of the thick plate.

The M825 pre-aged, stretched and aged meets the minimum contract strength goals. Increasing the amount of stretching from 1.5 to 3% reduction only slightly decreases the strength. Material not pre-aged before stretching has strengths 4 ksi lower than material pre-aged, however, material only roller leveled has strengths equal to the pre-aged material. Additional work is planned to determine if the minimum amount of stretching needed to achieve flatness will also permit desirable properties to be achieved, thereby permitting the deletion of the pre-aging treatment. The elongations observed for the plant fabricated M825 are lower than obtained with Laboratory material; no explanation for this is apparent.

The properties for M826 are dependent on product thickness and direction of testing. The strengths of the plant produced material are below the desired level; therefore, the 1.0" and 2.37" plate are being reheat treated and aged at

Alcoa Research Laboratories using a more severe aging practice (48 hours at 225°F).

Notch Toughness

Tensile and notch-tensile properties for 1.0" and 2.37" plate of M825 and M826 are shown in Table X. The notch-tensile ratio at -320°F for the 1.0" plate of M825 is lower than found previously using 0.5" thick Laboratory plate (Table IV). If the notch toughness retains the low temperature sensitivity characteristic of the 2000 series alloys, the toughness of M825 should be acceptable at -423°F. The notch toughness of the 2.37" plate of M825 is good, but due to its low strengths, the -423°F properties will not be determined.

The notch-tensile ratios of M826 are such at -320°F that they might be expected to reach the -423°F goal minimum of 0.9, but due to the low strengths the -423°F properties will not be determined. The material being re-worked using an isothermal aging treatment will be tested for notch toughness and if the properties are acceptable, -423°F testing will be done.

One unusual result obtained for the M826 material is the difference in temperature sensitivity of the strengths for the longitudinal and long transverse direction. The ratio of tensile and yield strength at -320°F to that at room temperature for the testing directions is as follows:

| | Longitudinal | Long Transverse |
|---|---|---|
| $TS_{-320}/TS_{RT}$ | 1.35 | 1.28 |
| $YS_{-320}/YS_{RT}$ | 1.25 | 1.19 |

The re-worked M826 plate will be tested in both directions to see if these results can be verified.

## ABSTRACT OF TECHNICAL CONTENT

An attempt to improve the weld strengths of 2000 series alloys by varying the filler alloy was unsuccessful. Alloys Al-Cu-Cd and Al-Cu-Cd-Sn (M825) welded as 0.125" sheet with 2319, M825 and Al-Cu fillers containing .23 Cd, .12 Mg or .53 Mg showed little variation in weld strength.

Deformation before aging may improve the notch toughness slightly for Al-Zn-Mg alloys with no Zr. The toughness of alloys containing Zr appears to be decreased slightly by cold working before aging.

Evaluation of the plant fabricated M825 has shown the following:

1. The 1.0" plate meets the minimum strength goal, but the 2.37" plate falls short, probably because of quench sensitivity.
2. The notch toughness is lower than determined previously for 0.525" Laboratory plate, but the -423°F goal minimum can probably be closely approached.
3. Material roller leveled but not stretched had properties equivalent to material pre-aged, stretched and aged. This indicates the possibility of eliminating the pre-aging treatment by employing only the minimum amount of leveling required. A program studying this is planned.

The M826 material had strengths lower than desired; therefore, material will be reheat treated at Alcoa Research Laboratories using an isothermal aging treatment of 48 hours at 225°F.

## ANTICIPATED WORK

Alloys Al-Cu-Cd and Al-Cu-Cd-Sn without Zr and V have been welded and the properties are being determined. This work was done to see if the lower quench sensitivity of the alloys without Zr and V would permit improved weld strengths. The reheat treatment of the M826 plate should be finished soon and all welding of M825 and M826 should be completed early in September. The fabrication of sheet, plate and weld wire for the second year program is underway.

During July, 1061.75 man-hours were expended on the programs described here.

TABLE I

NOMINAL COMPOSITIONS OF ALLOYS FOR SECOND-YEAR PROGRAM

| Series | S. No. | Cu | Si | Mn | Mg | Zn | Cr | Zr | V | Ti | Cd | Sn | Ni | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Phase I | | | | | | | | | | | | | | |
| Variations of M825 | | | | | | | | | | | | | | |
| | 292602 | 5.8 | | .30 | | | | .12 | .10 | .06 | .15 | .05 | | |
| | 292603 | 6.3 | | .30 | | | | .12 | .10 | .06 | .15 | .05 | | |
| | 292604 | 6.8 | | .30 | | | | .12 | .10 | .06 | .15 | .05 | | |
| | 292605 | 6.3 | | .30 | | | | .12 | .10 | .06 | .10 | .02 | | |
| | 292606 | 6.3 | | .30 | | | | .12 | .10 | .06 | .10 | .08 | | |
| | 292607 | 6.3 | | .30 | | | | .12 | .10 | .06 | .20 | .02 | | |
| | 292608 | 6.3 | | .30 | | | | .12 | .10 | .06 | .20 | .08 | | |
| Variations of M826 | | | | | | | | | | | | | | |
| | 292609 | .02 | | .20 | 1.8 | 6.5 | .12 | .12 | | .04 | | | | |
| | 292610 | .10 | | .20 | 1.8 | 6.5 | .12 | .12 | | .04 | | | | |
| | 292611 | .20 | | .20 | 1.8 | 6.5 | .12 | .12 | | .04 | | | | |
| | 292612 | .10 | | .20 | 1.8 | 6.5 | .12 | .06 | | .04 | | | | |
| | 292613 | .10 | | .20 | 1.8 | 6.5 | .12 | .18 | | .04 | | | | |
| | 292614 | .10 | | .20 | 1.4 | 6 | .12 | .12 | | .04 | | | | |
| | 292615 | .10 | | .20 | 2.2 | 7 | .12 | .12 | | .04 | | | | |
| Experimental Filler Alloys | | | | | | | | | | | | | | |
| | 292558 | 6.3 | | 0.7 | | | | .15 | .10 | .15 | | | 2.0 | |
| | 292559 | 8.0 | | 0.7 | | | | .15 | .10 | .15 | | | 2.0 | |
| | 292560 | 6.3 | | 0.7 | | | | .15 | .10 | .15 | .15 | .05 | 2.0 | |
| | 292561 | 6.3 | | 0.7 | 1.5 | | | .15 | .10 | .15 | | | 2.0 | |
| | 292562 | 6.3 | | 0.7 | 1.5 | 3.0 | | .15 | .10 | .15 | | | 2.0 | |
| | 292563 | 6.3 | 2.0 | 0.7 | 1.5 | | | .15 | .10 | .15 | | | | |
| | 292564 | 8.0 | | 0.7 | 1.5 | | | .15 | .10 | .15 | | | | |
| | 292565 | 8.0 | | 0.7 | | | | .15 | .10 | .15 | | | | |
| Phase II - Experimental Alloys | | | | | | | | | | | | | | |
| 2000 Series | | | | | | | | | | | | | | |
| | 292537 | 6.3 | | .3 | | | | .12 | .10 | .06 | .15 | .05 | | |
| | 292538 | 6.3 | | .3 | | | | .12 | .10 | .06 | .15 | .05 | | plus 0.3 Li |
| | 292539 | 6.3 | | .3 | | | | .12 | .10 | .06 | .15 | .05 | | plus 0.6 Li |
| 7000 Series | | | | | | | | | | | | | | |
| | 292540 | .10 | | .20 | 1.8 | 6.5 | .12 | .12 | | .05 | | | | |
| | 292541 | .10 | | .20 | 1.8 | 6.5 | .12 | .12 | | .05 | | | | plus 0.3 Li |
| | 292542 | .10 | | .20 | 1.8 | 6.5 | .12 | .12 | | .05 | | | | plus 0.3 Ag |
| | 292543 | .10 | | .20 | 1.8 | 6.5 | .12 | .12 | | .05 | | | | plus 0.3 Ca |

TABLE II

RESULTS OF CHEMICAL ANALYSIS

| Series | S. No. | Cu | Fe | Si | Mn | Mg | Zn | Cr | Zr | V | Ti | Cd | Sn | Ni | Analytical Report No. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2000 | | | | | | | | | | | | | | | |
| | 291597 | 6.16 | .17 | .07 | .29 | .31 | .00 | .00 | .17 | .11 | .06 | .00 | .00 | .01 | 63-120502 |
| | 291598 | 6.37 | .18 | .07 | .31 | .00 | .00 | .00 | .01 | .01 | .06 | .17 | .00 | .00 | 63-120502 |
| | 291599 | 6.27 | .18 | .07 | .28 | .00 | .00 | .00 | .00 | .01 | .06 | .15 | .05 | .00 | 63-120502 |
| | 291715 | 6.21 | .18 | .07 | .29 | .00 | .00 | .00 | .17 | .11 | .06 | .17 | .00 | .00 | 63-120502 |
| | 291716 | 6.24 | .18 | .07 | .28 | .00 | .00 | .00 | .17 | .11 | .06 | .14 | .05 | .00 | 63-120502 |
| | 291816 | 6.02 | .16 | .07 | .28 | .00 | .01 | .00 | .17 | .10 | .07 | --- | .04 | .00 | 64-010908 |
| 2000 (filler alloys) | | | | | | | | | | | | | | | |
| | 226038 | 6.32 | .18 | .11 | .30 | .00 | .02 | | .11 | .10 | .14 | .23 | | | |
| | 285399 | 6.16 | .19 | .09 | .29 | .12 | .00 | | .16 | .09 | .13 | | | | |
| | 285400 | 6.16 | .18 | .09 | .29 | .53 | .00 | | .15 | .09 | .14 | | | | |
| 7000 (previous alloys from Davenport) | | | | | | | | | | | | | | | |
| | M790 | .11 | .16 | .15 | .20 | 2.65 | 6.18 | .12 | .00 | | .01 | | | .00 | 63-081904 |
| | M791 | .12 | .16 | .09 | .21 | 2.22 | 6.20 | .13 | .10 | | .01 | | | .00 | 63-081904 |
| | M792 | .09 | .21 | .09 | .21 | 2.65 | 9.14 | .12 | .00 | | .02 | | | .00 | 63-081904 |
| | M793 | .12 | .18 | .09 | .21 | 1.64 | 6.51 | .13 | .10 | | .01 | | | .00 | 63-081904 |
| 7000 (filler alloy) | | | | | | | | | | | | | | | |
| | M822 | .01 | .17 | .06 | .34 | 2.25 | 5.91 | .01 | .14 | | .10 | | | .02 | |
| Alloys from Davenport | | | | | | | | | | | | | | | |
| | M825 | 6.48 | .15 | .10 | .34 | .00 | .02 | .00 | .12 | .08 | .06 | .12 | .06 | .00 | 64-062614 |
| | M826 | .14 | .16 | .10 | .23 | 2.03 | 6.62 | .12 | .11 | | .04 | | | .01 | 64-062614 |

TABLE III

WELD PROPERTIES OF 2000 SERIES ALLOYS

Welded 0.125" Sheet

| Alloy | Filler | Post Weld Age | Weld Bead On T.S. ksi | Y.S. ksi | % El. in 2" | Location+ of Failure | Weld Bead Off T.S. ksi | Y.S. ksi | % El. in 2" | Location+ of Failure |
|---|---|---|---|---|---|---|---|---|---|---|
| Al + Cu + Cd | 2319 | no* | 45.2 | 26.8 | 3.0 | B | 37.8 | 23.0 | 3.5 | A |
| | 2319 | 16 hrs./325°F** | 47.7 | 42.5 | 1.0 | B | 44.6 | 36.2 | 2.0 | B |
| | Al-6 Cu-.23 Cd | no | 44.6 | 25.6 | 4.0 | B | 39.2 | 22.3 | 4.2 | A |
| | Al-6 Cu-.23 Cd | 16 hrs./325°F | 48.6 | 40.8 | 1.8 | B | 44.8 | 34.7 | 3.0 | A,B |
| | Al-6 Cu-.12 Mg | no | 43.5 | 27.7 | 3.5 | B | 38.8 | 23.8 | 4.2 | A |
| | Al-6 Cu-.12 Mg | 16 hrs./325°F | 48.0 | 42.6 | 1.5 | B | 45.0 | 36.8 | 2.5 | A |
| | Al-6 Cu-.53 Mg | no | 46.8 | 28.8 | 3.8 | B | 38.6 | 25.8 | 3.5 | A |
| | Al-6 Cu-.53 Mg | 16 hrs./325°F | 51.8 | 41.3 | 1.8 | B | 44.3 | 34.9 | 2.5 | A |
| | Al-6 Cu-.14 Cd-.05 Sn | no | 41.8 | 27.3 | 3.0 | B | 34.7 | 23.2 | 3.0 | A |
| | Al-6 Cu-.14 Cd-.05 Sn | 16 hrs./325°F | 46.0 | 45.0 | 0.8 | B | 44.2 | 37.4 | 2.2 | A |
| Al + Cu + Cd + Sn | 2319 | no | 43.8 | 26.0 | 3.2 | B | 37.9 | 21.1 | 4.2 | A |
| | 2319 | 16 hrs./325°F | 51.0 | 43.3 | 1.5 | B | 44.8 | 36.6 | 2.2 | A |
| | Al-6 Cu-.23 Cd | no | 44.6 | 26.2 | 4.0 | B | 37.7 | 22.2 | 4.2 | A,B |
| | Al-6 Cu-.23 Cd | 16 hrs./325°F | 53.0 | 45.2 | 1.8 | B | 45.0 | 37.6 | 2.2 | A |
| | Al-6 Cu-.12 Mg | no | 44.8 | 26.7 | 3.5 | B | 37.4 | 23.1 | 4.5 | A |
| | Al-6 Cu-.12 Mg | 16 hrs./325°F | 47.4 | 40.7 | 1.5 | B | 43.9 | 34.2 | 2.8 | A |
| | Al-6 Cu-.53 Mg | no | 44.0 | 27.8 | 3.5 | B,C | 37.8 | 25.0 | 3.2 | A |
| | Al-6 Cu-.53 Mg | 16 hrs./325°F | 49.5 | 39.9 | 1.5 | B | 43.9 | 34.1 | 2.5 | A |
| | Al-6 Cu-.14 Cd-.05 Sn | no | 42.4 | 26.7 | 2.8 | B | ---- | 21.3 | 2.0 | A |
| | Al-6 Cu-.14 Cd-.05 Sn | 16 hrs./325°F | 49.6 | 46.0 | 1.0 | B,C | 44.2 | 37.6 | 1.5 | A,B |

* Room temperature aged about 25 days.

** Post-weld aged about 2 weeks after welding.

\+ Location of failure
A thru weld
B thru edge of weld
C parent metal

1. Thermal treatment of parent metal: both alloys solution heat treated 30 min. at 995°F and cold water quenched; 2219 + Cd - pre-aged 1 hr. at 325°F, stretched, and aged 16 hrs. at 325°F; 2219 + Cd + Sn - stretched and aged 8 hrs. at 325°F.
2. Composition of parent metal given in Table II using the following designation; 2219 + Cd - 291715; 2219 + Cd + Sn - 291716.
   Composition of filler alloys also given in Table II. The 2219 + Cd + Sn filler is the same as the 2219 + Cd + Sn parent metal.
3. Welded in the longitudinal direction - transverse specimens - Y.S. = 0.2% offset (centered on weld).

TABLE IV

TENSILE PROPERTIES OF 2000 SERIES ALLOYS

Smooth and Notched Specimens from 0.525" Plate

| S. No. | Alloy | Pre-age Time hr. | Pre-age Temp. °F | Stretch % | Age Time hr. | Age Temp. °F | Testing Temp. | T.S. ksi | Y.S. ksi | % El. in 4D | % R of A | NTS+ ksi | NTS++ TS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 291818 | Cu-Cd | 1 | 325 | 1 1/2 | 16 | 325 | RT | 73.8 | 60.8 | 11.4 | 18 | 81.1 | |
| | | | | | | | | | | | | 83.4 | 1.13 |
| | | | | | | | -112°F | 77.0 | 62.8 | 12.3 | -- | 86.3 | |
| | | | | | | | | | | | | 88.2 | |
| | | | | | | | | | | | | 90.0 | 1.17 |
| | | | | | | | -320°F | 88.0 | 69.8 | 13.3 | 16 | 94.8 | |
| | | | | | | | | | | | | 95.4 | 1.08 |
| | | | | | | | -423°F | 102 | 76.1 | 13.5 | 16.9 | 102 | 1.00 |
| 291819 | Cu-Cd-Sn (M825) | - | --- | 1 1/2 | 8 | 325 | RT | 73.0 | 61.3 | 10.0 | 14 | 72.1 | |
| | | | | | | | | | | | | 75.6 | 1.03 |
| | | | | | | | -112°F | 76.4 | 64.0 | 11.6 | -- | 85.3 | 1.12 |
| | | | | | | | -320°F | 90.0 | 73.9 | 12.5 | 15 | 92.1 | |
| | | | | | | | | | | | | 94.5 | |
| | | | | | | | | | | | | 97.7 | 1.08 |
| | | | | | | | -423°F | 103 | 80.1 | 12.5 | 16.7 | 103 | 1.00 |
| 291905 | Cu-Cd-Sn (M825) | 1 1/2 | 300 | 1 1/2 | 8 | 325 | RT | 75.4 | 66.0 | 9.0 | 12 | 74.1 | .98 |
| | | | | | | | -112°F | 80.4 | 71.6 | 9.3 | -- | 82.7 | |
| | | | | | | | | | | | | 84.4 | |
| | | | | | | | | | | | | 87.3 | 1.08 |
| | | | | | | | -320°F | 89.8 | 73.8 | 12.7 | 15 | 93.5 | |
| | | | | | | | | | | | | 95.1 | 1.06 |
| | | | | | | | -423°F | 99.1 | 82.8 | 10.0 | 14.5 | 102 | 1.03 |

\+ All test values are included if there were large deviations among them, otherwise, the value listed is the average.

++ The highest notch-tensile strength was used if all test values are listed.

1. Transverse properties - Y.S. = 0.2% offset - Notched round specimen, $K_t$ = 10, ARL Dwg. L-9178.
2. Ingot S. Nos.: Cu-Cd, 291715; Cu-Cd-Sn, 291716.

TABLE V

TENSILE PROPERTIES OF COMMERCIAL ALLOYS

(1.0 to 1.25" Plate)

| Alloy and Temper | Testing Temp. | T.S. ksi | Y.S. ksi | % El. in 2" | % R of A | NTS ksi | NTS TS |
|---|---|---|---|---|---|---|---|
| 2219-T851 | RT | 68.8 | 52.1 | 10.2 | 16 | 80.3 | 1.17 |
| | -112°F | 74.5 | 58.8 | 9.2 | 17 | 78.3 | |
| | | | | | | 79.3 | |
| | | | | | | 80.7 | 1.08 |
| | -320°F | 85.2 | 63.7 | 11.5 | 19 | 90.7 | |
| | | | | | | 91.8 | 1.08 |
| 2219-T87 | RT | 67.6 | 56.0 | 10.5 | 20 | 76.6 | 1.13 |
| | -112°F | 72.6 | 59.4 | 9.8 | 18 | 76.7 | |
| | | | | | | 79.8 | 1.10 |
| | -320°F | 85.0 | 67.6 | 11.0 | 18 | 83.4 | |
| | | | | | | 84.9 | |
| | | | | | | 87.3 | 1.03 |
| | -423°F | 99.4 | 72.2 | 13.5 | 18 | 91.9 | |
| | | | | | | 92.5 | |
| | | | | | | 93.9 | .94 |
| X7106-T6351 | RT | 65.6 | 58.1 | 12.8 | 29 | 89.0 | 1.36 |
| | -112°F | 74.6 | 64.8 | 13.0 | 25 | 93.8 | 1.26 |
| | -320°F | 86.8 | 70.5 | 14.0 | 20 | 90.9 | |
| | | | | | | 91.7 | 1.06 |
| | -423°F | 102.5 | 75.0 | 15.2 | 17 | 94.5 | |
| | | | | | | 95.5 | |
| | | | | | | 96.5 | .94 |
| X7139-T6351 | RT | 68.0 | 58.6 | 12.5 | 28 | 86.8 | 1.28 |
| | -112°F | 76.2 | 64.7 | 11.2 | 21 | 79.7 | |
| | | | | | | 80.0 | |
| | | | | | | 83.3 | 1.09 |
| | -320°F | 88.2 | 70.4 | 10.5 | 14 | 79.8 | |
| | | | | | | 82.6 | .94 |

\+ All test values are included if there were large deviations among them; otherwise, the value listed is the average

++ The highest notch-tensile strength was used if all test values are listed.

1. Transverse properties - Y.S. = 0.2% offset - Notched round specimens, $K_t$ = 10, ARL Dwg. L-9178.

TABLE VI

WELD PROPERTIES OF 7000 SERIES ALLOYS

Full and Reduced Section

| S. No. | Alloy | Welding Method | Condition* of Weld | Full Section Prop. T.S. ksi | Full Section Prop. Location+ of Failure | Reduced Section Prop.** T.S. ksi | Reduced Section Prop.** Location of Failure |
|---|---|---|---|---|---|---|---|
| 292058-A1 | M791 | MIG | -1 | 60.8 | B | 59.2 | C |
| 292058-A2 | M791 | MIG | -2 | 60.8 | B | 60.6 | C |
| 292058-A3 | M791 | MIG | -3 | 61.2 | B | ---- | - |
| 292058-B1 | M791 | TIG | -1 | 55.5 | B | 55.8 | C |
| 292058-B2 | M791 | TIG | -2 | 59.0 | C | 54.6++ | C |
| 292058-B3 | M791 | TIG | -3 | 60.0 | C | ---- | - |
| 292059-A1 | M793 | MIG | -1 | 58.0 | B-C | 54.8++ | C |
| 292059-A2 | M793 | MIG | -2 | 57.7 | C | 57.7 | C |
| 292059-A3 | M793 | MIG | -3 | 59.2 | C | ---- | - |
| 292059-B1 | M793 | TIG | -1 | 52.8 | C | 53.0 | C |
| 292059-B2 | M793 | TIG | -2 | 56.8 | C | 51.9++ | C |
| 292059-B3 | M793 | TIG | -3 | 56.5 | C | ---- | - |

* -1 As-welded, naturally aged over 2 months.
-2 Post-weld aged after one month at room temperature 8 hrs. at 225°F + 16 hrs. at 300°F.
-3 Post-weld aged after one month at room temperature 48 hrs. at 250°F.

** Round reduced section specimens.

\+ -B At edge of the weld.
-C Adjacent to weld zone (in heat affected zone).

++ No apparent reason for these strengths being lower than the full section strengths.

TABLE VII

EFFECT OF DEFORMATION BEFORE AGING ON TENSILE PROPERTIES

| Sample Designation | Alloy | Quench | Deformation Interval* | Deformation Amount | Room Temperature TS ksi | Room Temperature YS ksi | Room Temperature % El. in 2" | Room Temperature NTS/ ksi | Room Temperature NTS// TS | -320°F TS ksi | -320°F YS ksi | -320°F % El. in 2" | -320°F NTS/ ksi | -320°F NTS// TS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 292419-1 | M790 | BWQ | None | 10% | 76.0 | 70.6 | 9.5 | 65.7<br>66.0 | | 95.8 | 88.2 | 6.0 | 48.6<br>57.0 | |
| -3 | M790 | BWQ | 3 da | 10% | 77.2 | 71.6 | 9.5 | 68.3<br>70.6<br>72.6 | .90 | 96.6 | 88.2 | 4.5 | 57.8<br>48.1<br>52.5 | .60 |
| 291321-D | M790 | BWQ | -- | -- | 77.2 | 71.0 | 11.0 | 73.0<br>70.7 | .94<br>.92 | 94.2 | 83.7 | 5.0 | 57.2<br>45.2 | .59 |
| -G | M790 | CWQ | -- | -- | 78.4 | 72.6 | 10.5 | 74.1<br>77.2 | | 96.0 | 89.7 | 4.8 | 47.7<br>52.8<br>39.9 | .56 |
| | | | | | | | | 78.0 | .99 | | | | 42.9<br>43.5 | .45 |
| 292209-1 | M791 | BWQ | None | 10% | 75.8 | 70.8 | 9.0 | 74.8 | .99 | 99.0 | 87.5 | 10.0 | 63.1 | |
| -3 | M791 | BWQ | 3 da | 10% | 75.6 | 70.3 | 8.8 | 74.0 | .98 | 100.1 | 89.1 | 10.0 | 63.3<br>60.7 | .63 |
| -2 | M791 | CWQ | None | 10% | 77.8 | 73.7 | 9.0 | -- | -- | 101.5 | 92.6 | 10.0 | 63.6<br>64.5<br>59.6 | .64 |
| -4 | M791 | BWQ | Before** SHT | 10% | 77.4 | 72.6 | 9.2 | 72.4<br>74.0 | | 98.0 | 90.9 | 6.2 | 66.4<br>66.6<br>58.1 | .66 |
| -5 | M791 | BWQ | Before*** SHT | 40% | 77.2 | 72.0 | 11.2 | 77.0<br>77.1<br>77.3 | .99 | 99.0 | 85.2 | 8.2 | 58.3<br>62.9<br>37.0 | .64 |
| | | | | | | | | 79.3 | 1.03 | | | | 45.0<br>46.0 | .46 |
| 291246-D | M791 | BWQ | -- | -- | 78.8 | 73.8 | 10.0 | 68.7<br>70.1 | | 100.2 | 88.9 | 9.0 | 61.9<br>65.5 | |
| -G | M791 | CWQ | -- | -- | 80.2 | 76.4 | 9.5 | 75.0<br>73.4 | .95<br>.92 | 102.3 | 92.2 | 9.0 | 68.4<br>64.8 | .68<br>.63 |
| 292208-1 | M793 | BWQ | None | 10% | 71.4 | 67.8 | 8.5 | 74.8 | 1.05 | 94.9 | 82.0 | 10.5 | 73.2 | |
| -3 | M793 | BWQ | 3 da | 10% | 71.8 | 67.9 | 9.0 | 73.6 | 1.02 | 94.4 | 85.7 | 10.0 | 74.1<br>71.0 | .78 |
| 291319-D | M793 | BWQ | -- | -- | 75.4 | 70.5 | 10.0 | 72.0<br>74.8 | | 95.5 | 87.5 | 8.2 | 74.1<br>69.6<br>74.3 | .78 |
| -G | M793 | CWQ | -- | -- | 75.4 | 71.8 | 9.2 | 75.9<br>76.4 | 1.01<br>1.01 | 97.4 | 87.2 | 7.8 | 77.2<br>78.8<br>80.3 | .81<br>.82 |

* Interval between quenching and deformation.

** Completely recrystallized, cold rolled 10% and then solution heat treated, X-ray pinhole examination showed the material remained unrecrystallized.

*** Completely recrystallized, cold rolled 40% and then solution heat treated, X-ray pinhole examination showed the material had started to recrystallize.

/ All test values were included if there were large deviations among them; otherwise, the value listed is the average.

// Highest notch tensile strength used if all test values are listed.

1. All material solution heat treated for 30 min at 860°F, quenched and aged after 3 da 48 hr at 250°F.
2. Transverse properties - YS = 0.2% Offset - Notch sheet specimens, $K_t$ = 10, ARL Dwg D-9177.

TABLE VIII

TENSILE PROPERTIES OF M825

| S. No. | Thickness inches | Pre-age Time hr. | Pre-age Temp. °F | Roller Level | Stretch | Age Time hr. | Age Temp. °F | Direction | T.S. ksi | Y.S. ksi | % El. in 4D | % R of A |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 292510 | .125 | 1 | 300 | yes | 1.5 max. | 10 | 325 | L | 72.2 | 62.6 | 10.0 | |
| | | | | | | | | LT | 72.8 | 62.4 | 9.8 | |
| 292492 | .500 | 1 | 300 | yes | 1.5 max. | 10 | 325 | L | 73.6 | 64.6 | 8.2 | |
| | | | | | | | | LT | 73.6 | 62.8 | 8.5 | |
| 292490 | 1.0 | 1 | 300 | yes | 1.5 max. | 10 | 325 | L | 75.9 | 68.6 | 7.0 | 10 |
| | | | | | | | | LT | 75.9 | 66.8 | 5.0 | 6.0 |
| 292491 | 1.0 | 1 | 300 | yes | 1.5 - 3.0 | 10 | 325 | L | 75.5 | 66.4 | 7.5 | 10 |
| | | | | | | | | LT | 75.6 | 65.9 | 6.0 | 6 |
| 292495 | 1.0 | no | no | yes | no | 10 | 325 | L | 73.8 | 66.0 | 7.5 | 9 |
| | | | | | | | | LT | 73.6 | 65.7 | 5.5 | 6 |
| 292493 | 1.5 | 1 | 300 | yes | 1.5 max. | 10 | 325 | L | 74.2 | 66.2 | 7.5 | 10 |
| | | | | | | | | LT | 72.8 | 65.7 | 3.8 | 6 |
| | | | | | | | | ST | 71.1 | 66.6 | 3.1 | 4 |
| 292421 | 1.5 | no | no | yes | 1.5 max. | 10 | 325 | L | 72.5 | 62.7 | 8.2 | 12 |
| | | | | | | | | LT | 72.2 | 61.6 | 7.0 | 8 |
| | | | | | | | | ST | 71.1 | 62.0 | 4.7 | 6 |
| 292494 | 1.5 | no | no | yes | no | 10 | 325 | L | 74.6 | 66.4 | 7.2 | 10 |
| | | | | | | | | LT | 73.5 | 66.2 | 5.0 | 7 |
| | | | | | | | | ST | 71.4 | 67.2 | 2.7 | 5 |
| 292489 | 2.37 | 1 | 300 | yes | 1.5 max. | 10 | 325 | L | 70.8 | 61.0 | 8.0 | 11.0 |
| | | | | | | | | LT | 70.6 | 60.8 | 4.8 | 6.0 |
| | | | | | | | | ST | 68.1 | 62.5 | 3.0 | 6.0 |

1. All material solution heat treated at 995°F and cold water quenched.
2. Y.S. = 0.2% offset.

TABLE IX

TENSILE PROPERTIES OF M826 SHEET AND PLATE
FROM DAVENPORT

| S. No. | Thickness inches | Direction | T.S. ksi | Y.S. ksi | % El. in 2" | % R of A |
|---|---|---|---|---|---|---|
| 292460 | .125 | L | 72.4 | 65.8 | 11.0 | |
| | | LT | 70.6 | 64.4 | 12.8 | |
| 292547 | .500 | L | 69.4 | 63.9 | 16.0 | |
| | | LT | 67.2 | 61.8 | 14.0 | |
| 292459 | 1.0 | L | 70.5 | 63.8 | 14.2 | 38 |
| | | LT | 67.5 | 59.4 | 13.8 | 32 |
| 292550 | 1.5 | L | 70.1 | 64.0 | 13.0 | 26 |
| | | LT | 67.6 | 60.7 | 12.2 | 24 |
| | | ST | 65.8 | 55.4 | 7.0 | 16 |
| 292458 | 2.37 | L | 66.4 | 58.8 | 13.2 | 28 |
| | | LT | 65.1 | 55.9 | 11.5 | 22 |
| | | ST | 65.4 | 55.1 | 7.0 | 10 |

1. All material solution heat treated at 860°F and aged 8 hrs. at 225°F plus 16 hrs. at 300°F.
2. Y.S. = 0.2% offset.

TABLE X

TENSILE AND NOTCH-TENSILE DATA FOR PLANT PRODUCED ALLOYS

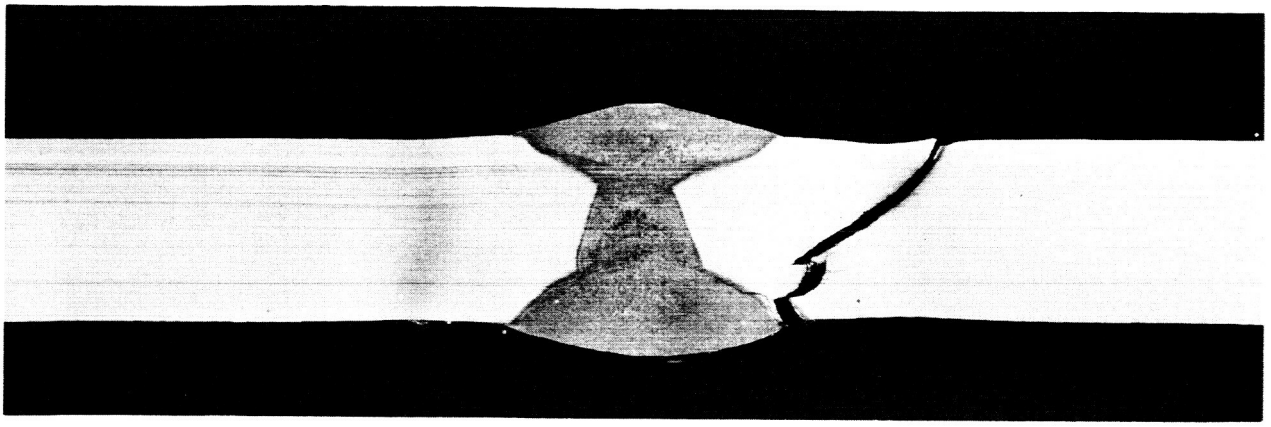
| | | | | Longitudinal | | | | | | Long Transverse | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| S. No. | Alloy | Thickness | Testing Temp. | TS ksi | YS ksi | % El. in 4D | % R of A | NTS/ ksi | NTS// TS | TS ksi | YS ksi | % El. in 4D | % R of A | NTS/ ksi | NTS// TS |
| 292490 | M825 | 1.0" | RT | 75.9 | 68.6 | 7.0 | 10 | 81.3 | 1.07 | 75.9 | 66.8 | 5.0 | 6 | 72.3 | .95 |
| | | | -112°F | -- | -- | -- | -- | -- | -- | 80.2 | 70.8 | 5.0 | 8 | 71.8 | |
| | | | | | | | | | | | | | | 80.4 | |
| | | | | | | | | | | | | | | 82.2 | 1.02 |
| | | | -320°F | 91.2 | 81.2 | 9.5 | 14 | 90.7 | | 92.2 | 80.0 | 6.0 | 8 | 75.7 | |
| | | | | | | | | 92.2 | | | | | | 80.8 | |
| | | | | | | | | 93.0 | 1.02 | | | | | 84.3 | .91 |
| | | | -423°F | -- | -- | -- | -- | -- | -- | * | * | * | * | * | * |
| 292489 | M825 | 2.37" | RT | 70.8 | 61.0 | 8.0 | 11 | 77.5 | 1.09 | 70.6 | 60.8 | 4.8 | 6 | 68.9 | .98 |
| | | | -112°F | -- | -- | -- | -- | -- | -- | 75.7 | 63.9 | 5.7 | 9 | 77.3 | |
| | | | | | | | | | | | | | | 79.3 | |
| | | | | | | | | | | | | | | 81.1 | 1.07 |
| | | | -320°F | 86.0 | 72.1 | 11.2 | 18 | 90.4 | | 87.4 | 71.1 | 8.0 | 12 | 81.5 | |
| | | | | | | | | 97.4 | | | | | | 82.2 | |
| | | | | | | | | 97.4 | 1.13 | | | | | 85.9 | .98 |
| 292459 | M826 | 1.0" | RT | 70.5 | 63.8 | 14.2 | 38 | 93.1 | 1.39 | 67.5 | 59.4 | 13.8 | 32 | 89.2 | 1.32 |
| | | | -112°F | -- | -- | -- | -- | -- | -- | 73.4 | 61.9 | 12.0 | 21 | 89.8 | |
| | | | | | | | | | | | | | | 89.8 | |
| | | | | | | | | | | | | | | 91.4 | 1.24 |
| | | | -320°F | 94.2 | 79.2 | 13.0 | 17 | 104.8 | 1.11 | 86.2 | 69.0 | 12.7 | 18 | 90.4 | |
| | | | | | | | | | | | | | | 93.2 | |
| | | | | | | | | | | | | | | 96.2 | 1.12 |
| 292458 | M826 | 2.37" | RT | 66.4 | 58.8 | 13.2 | 28 | 91.8 | 1.38 | 65.1 | 55.9 | 11.5 | 22 | 85.6 | 1.31 |
| | | | -112°F | -- | -- | -- | -- | -- | -- | 71.2 | 59.6 | 9.5 | 15 | 84.4 | |
| | | | | | | | | | | | | | | 85.2 | |
| | | | | | | | | | | | | | | 86.4 | 1.21 |
| | | | -320°F | 90.2 | 73.9 | 11.5 | 15 | 95.0 | | 84.1 | 67.6 | 8.2 | 11 | 83.4 | |
| | | | | | | | | 96.4 | | | | | | 85.7 | |
| | | | | | | | | 100.2 | 1.11 | | | | | 85.7 | 1.02 |

* To be determined.

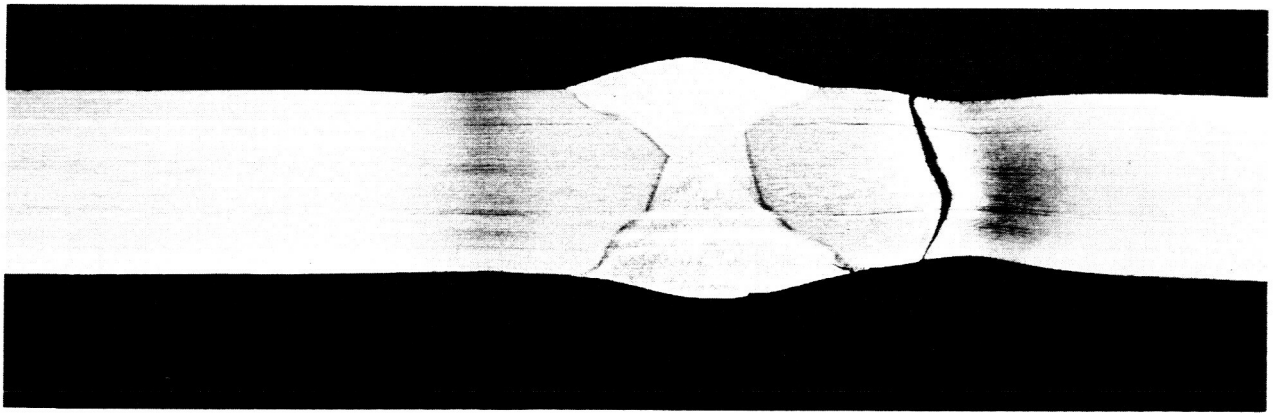
/ All test values were included if there were large deviations among them; otherwise, the value listed is the average.

// Highest notch tensile strength used if all test values are listed.

1. Material described in Tables VIII and IX.
2. YS = 0.2% Offset - Notched round specimens, $K_t$ = 10, ARL Dwg L-9178.



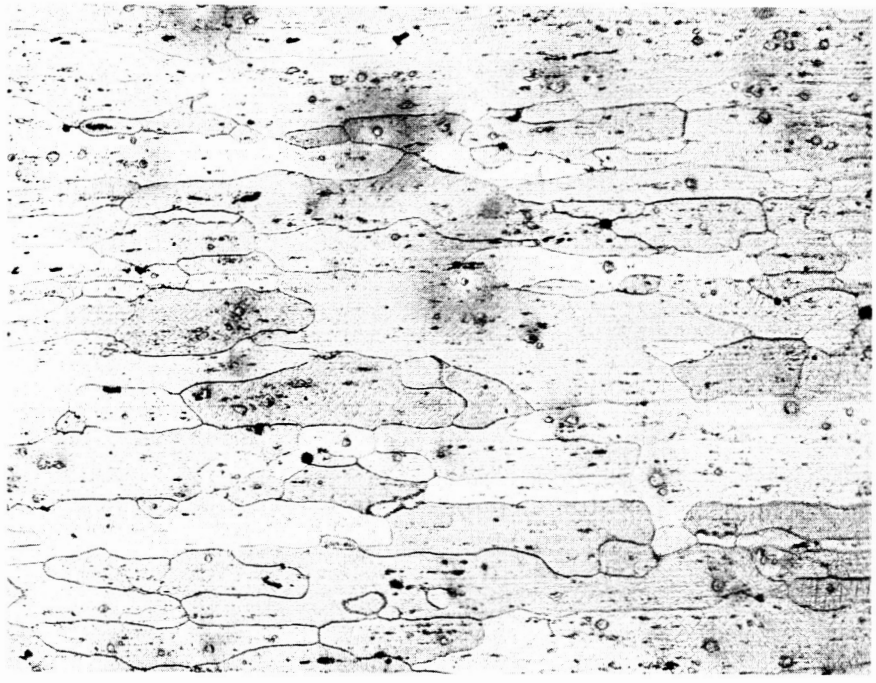
292058-A2-F1 Flick's Etch 2X



292059-A1-F1 Flick's Etch 2X

Figure 1 - Macrographs showing tendancy of 7000 series alloy welds to fail at two locations (0.525" welded plate).

141791AJ



292490 Keller's Etch 100X

292459 Keller's Etch 100X

141835J
141836J

Figure 2 - Micrographs of M825 (top) and M826 (bottom) 1.0" plate